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FERTILIZATSIYA OZER NA KAMCHATKE

THE FERTILIZATION OF LAKES IN KAMCHATKA

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The fertilization of lakes - one of the methods of pastural fishery - so far is at an experimental stage and used in practice only for one species of Pacific salmon, the sockeye (Oncorhynchus nerka) which, unlike the other species of this genus, spawns and spends the initial period of feeding and growing in lakes, foraging mostly on pelagic zooplankton. Lakes, as a rule, respond positively to enrichment of their waters by biogens that enhance their biological productivity, and are amenable to economic and limnological control. In the course of fertilization, a nummer of hypotheses and theoretical tenets held by limnologists at various times can be tested. In the past decade, much has been done in this direction by specialists of the Canadian and American fishery services. The theoretical foundation of the method was supplied by E.M. Krokhin (1967) who used as an example Lake Dal'nee in Kamchatka. Among other things, he showed that the balance of a very important biogen - phosphorus - in the lakes depends to a considerable degree on the numbers of sockeye salmon that enter the lake for spawning.

The impoverishment of lake waters in biogens lowers the level of trophodynamic processes in the lake's ecosystem. A long-term shortage of phosphorus threatens to reduce the fish populations, to cause a deterioration of quality and an undesirable ecological restructuring of the populations.

This is exactly what happened to the local populations of sockeye practically in all the lakes of the Kamchatka peninsula in the period of intensive fishing by the Japanise at open sea during the 60's and 70's. In particular, adversely affected were the Asian populations of sockeye which reproduce in Lake Kuril. The escapement of fishes to the spawning grounds dropped here by 100% and the annual loss of phosphorus amounted to about 0.2mg/m^3.

E.M. Krokhin proposed to eliminate the shortage of phosphorus by introducing into the lake mineral phosphorus-containing fertilizers. /2
By that time there appeared the first publications documenting successful experiments with lake fertilization (Nelson, Edmondsen, 1955). The feasibility of that method was confirmed by the natural fertilization of sockeye-sustaining Lake Azabach'e in the Kamchatka River basin where, after an ashfall in 1956, a sharp increase in the number of diatom algae was observed (from 10000 to one million cells per one liter). The production wave in 1956-1964 could be traced at all three trophic levels: in 1961-1965 there was an increase in the numbers of pelagic crustaceans - copepods and water-fleas, and in 1965-1969 there was a 4-5-fold increase, in comparison with the average for several years, in the number of spawning runs of sockeye.

That the above-mentioned events were not accidental was proved by the subsequent eruptions and ashfalls on the same lake in 1975 and 1976, the impact on the returning sockeye in higher numbers in 1982-1985 being even more impressive.

Experiments on fertilization could begin only in 1980. For the first test, the small (220 ha) Lake Listvennichnoe on the southeastern coast of the peninsula was chosen.

The main purpose of the experiment was the reversibility of the ecosystem: whether it would return to its former condition after fertilization or would certain chenges be apparent.

The lake is located in a narrow mountain valley. It is of glacial-fjord origin, is separated from the sea by a pebble dike 700-1200 m in width. The average depth is of 16.2 m, the maximum depth - 28m. The lake

is dimictic, the epilimnion reaches 7-10 m and has a surface temperature of up to 16°, rarely 18°. The water is slightly acid (pH = 6.7-7.0). The lake is oligotrophic, samples for phosphate and nitrate content almost always showed an analytical zero. The biomasses of phytoplankton and zooplankton are minimal in comparison with the corresponding indexes of other lakes we have studied.

The phytoplankton basically is represented by diatoms, whereas in the crustacean plankton Holopedium gibberum is dominant; the size of the /3
sockeye population (catch plus spawning run) in 1970-1980 was on the average five (from three to seven) thousand specimens (at the spawning grounds the fish were counted from the helicopter).

The fertilizers were spread from the boat right after the lake was opened on June 26, then on July 3 and July 9, 1980. 2.2 tons of superphosphate and carbamide in equal parts were introduced.

The calculated quantity of phosphorus introduced was 0.095 g/m^2, of nitrogen - 0.07g/m^2, which was far from the critical mark of eutrophication (1.18 after Folenweider) and slightly less than the amount introduced into Great Central Lake of British Columbia.

The experiment had the following consequences: the quantity of algae increased by one order during the year of introduction and in subsequent years dropped practically to the initial level and then began to increase slightly in 1984-1986 which, apparently is explained by autoeutrophication provoked by the more frequent entry of sockeye salmon in those years.

The size of the second trophic link - holopedium - increased 2-3-fold during the year of fertilizer introduction. Its fertility increased 1.5-fold and, in 1981, its size reached the maximum (six times higher than the initial); in subsequent years it began to drop, but not as abruptly as that of the algae. Most probably, holopedium feeds not only on algae but also on bacteria, the quantity of which we have not estimated.

A small improvement in the feeding conditions for juvenile sockeye in 1980 had a favorable effect on the age of spawners in 1983, and the great abundance of holopedium in 1981 was responsible for the unusual return for this water basin of 28000 specimens, which is about six times higher than

the initial level. Subsequently the number of returning fish began to drop, but it increased again in 1987, which may be explained by the higher ingress of biogens from fish carcasses in 1983 and 1984.

The size of the fishes in the postfertilization period increased on the average by 0.51 kg, and sometimes by more than 1 kg. Improved growth was observed in smolts. The maturation of fish was accelerated, in particular the higher-age group (6_3+ and 7_3+) disappeared from the runs. /4

Thus, there are all reasons to believe that the first experiment in fertilization was a success. It has confirmed, among other things, that the conditions of the lake's ecosystem that had changed following fertilization are reversible and present no threat to the lake.

Our next experimental body of water was Lake Kuril. It has an area of 75 km^2, an average depth of 184 m, a maximum depth of 320 m, a volume of 14 km^3 and is connected to the Sea of Okhotsk by the Ozernaya River (length - 50 km, average annual flow - 25 m^2). The lake is dimictic, the fall homothermy is established in the second half of November; in December the reversed stratification is established with a temperature of about 3° at a depth of 200 m. /5

The spring homothermy is established in late May-June, 5-8 days after the ice melts. The lower boundary of the epilimnion fluctuates from 20 to 140 m. In some years the lake does not freeze.

In hydrochemical terms, the water of the lake displays all the features of an oligotrophic body of water. The pH value is usually 7-8. The saturation of water with oxygen at all depths is close to normal. The water is soft, of hydrocarbonate class, with a mineral content of only 65-76 mg/l.

The content of phosphates is close to the analytic zero, in September-october up to 8-10 mkg/l.

The lake is of volcanic origin with thermal springs at the northeastern coast. Similar springs have been discovered at a depth of about 300 m. This fact may favor an increased dynamics of lake water.

In its morphology, Lake Kuril is close to the Canadian Lake Great Central

(area, average and maximum depths), but the thermocline in Lake Luril is not as prominent and the temperature of its epilimnion is lower, which makes it more accessible for juvenile sockeye.

In the phytoplankton of the lake the alga Melosira italica is clearly dominant, in the zooplankton prevails the copepod Cyclops scutifer, which constitutes the basic feed for juvenile sockeye. During the fall-winter period another pelagic crustacean - Daphnia longiremis- is of great importance in this regard.

Fertilizers were first introduced in March-April 1981. Superphosphate and carbomide in equal parts (40 tons each) were dusted from an aircraft on the ice of the lake in the Severnaya Bay. We thought that being on the wet ice before it melted would help this poorly soluble fertilizer to pass faster into the solution. /6

All that remained was waiting for the ice to melt and observing the consequences of the experiment. However, certain unexpected events strongly affected the course of the experiment: in late April there was a powerful eruption of the Alaid volcano located at the Atlasov Island, 150 km to the southwest of the lake. The volcanic ashes were carried north by the wind and fell partly on the basin of Lake Kuril. The average ashfall was of 1 kg/m^2, and the total amount that fell on the basin was of about 300000 tons.

The influence of the ashes on the hydrological and ecological systems of the lake was twofold: first of all, it caused an early opening of the lake as a result of diminished albedo of the lake ice (the ice broke up a month earlier) advancing the usual phenological dates in the ecological cycles of plankton organisms. Secondly, the lake water was enriched by the chemical compounds from the ashes. Their effect on the level of primary production was multiple. Basically, these compounds were chemically neutral (about 90% $CaSO_4$, however, 320 tons of chlorine, 16 tons of fluorine and, most importantly, about 20 tons of free sulfuric acid had inhibited the course of productive processes in the lake. The phosphorus content (about 2 tons) was lower than in the fertilizers introduced, but manganese, iron, magnesium, and silicon which stimulate photosynthesis and also, in all probability, many microelements undoubtedly had a favorable effect on the growth

of primary production. However, this came to light only next year, in 1982, when the active compounds had been neutralized. It must be noted that in the fall of 1981 freshets caused by torrential rain filled the lake water with organic substances washed from the slopes of the basin.

In 1982, an additional 100 tons of superphosphate were introduced in the lake. We decided not to use nitric fertilizers, since the laboratory /7
modeling showed a curious phenomenon of "nitric inhibition"; an addition of nitrogen-containing salts hampered the assimilation of phosphorus. Apparently this phenomenon depended on the effect of ash extracts. In the following years no such effect was observed and we started using a combination fertilizer Ammophos ($PH_4H_2PO_4$).

In 1983 and 1984, for technical reasons, no fertilizers were introduced, and in 1985 50 tons of Ammophos were introduced. Moreover, in 1984 2.75 million fishes entered the lake for spawning, which is equivalent to 22 tons of P_2O_5. This precipitated in 1986 an abrupt increase in the size of primary production: the abundance of melosira reached an incredible level - more than two billion cells per cubic meter.

There was an unusual increase in the number of copepods that reached an all-time high in 1985.

The improvement in the food supply was accompanied by a higher quality of smolt, viz. of their size and fullness.

A considerable increase in the number of returning adult sockeye occurred in 1984. The subsequent growth of this population is shown in the following table.

In 1987 the size of the population was at a level close to the all- /8
time high.

During the postfertilization period an increase in body size and a certain rejuvenation of the population were observed.

Thus, the fertilization helped reestablish the sockeye population at its previous natural level. At present, other sockeye lakes in Kamchatka are being studied with a view to a possible application of these measures.

Size of the population of the Ozernaya River before and after fertilization

Year	Period	Catch in Ozernaya		Japanese catch	Escapement to spawning grounds	Overall size of population
		thousand specimens	thousand specimens	thousand specimens		
1	2	3	4	5	6	7
1978	before	245	613	725	1450	2420
1979	fertiliza-	220	550	845	1350	2415
1980	tion	500	1250	773	1500	2773
1981	of fertili-	550	1375	740	1250	2540
1982	zation	457	1125	587	750	1794
1983		518	1333	583	1650	2751
1984	after ferti-	933	2685	477	2750	4160
1985	lization	2504	6251	331	3420	6255
1986		1900	4500	400	2350	4650
1987		3200	8000	400	3000	6600